Contribution to the Development of Methodology for Sampling and Tagging Small Juvenile Lobsters *Homarus americanus*

Brock B. Bernstein and Alan Campbell

Biological Station,
St. Andrews, N. B., EOG 2XO

December 1983

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1741

Canadian Manuscript Report of Fisheries and Aquatic Sciences

These reports contain scientific and technical information that represents an important contribution to existing knowledge but which for some reason may not be appropriate for primary scientific (i.e. *Journal*) publication. They differ from Technical Reports in terms of subject scope and potential audience: Manuscript Reports deal primarily with national or regional problems and distribution is generally restricted to institutions or individuals located in particular regions of Canada. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries management, technology and development, ocean sciences, and aquatic environments relevant to Canada.

Manuscript Reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report will be abstracted by *Aquatic Sciences and Fisheries Abstracts* and will be indexed annually in the Department's index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 901-1425 were issued as Manuscript Reports of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Details on the availability of Manuscript Reports in hard copy may be obtained from the issuing establishment indicated on the front cover.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution importante aux connaissances actuelles mais qui, pour une raison ou pour une autre, ne semblent pas appropriés pour la publication dans un journal scientifique. Ils se distinguent des Rapports techniques par la portée du sujet et le lecteur visé; en effet, ils s'attachent principalement à des problèmes d'ordre national ou régional et la distribution en est généralement limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du Ministère des Pêches et des Océans, notamment gestion des pêches; techniques et développement, sciences océaniques et environnements aquatiques, au Canada.

Les Manuscrits peuvent être considérés comme des publications complètes. Le titre exact paraît au haut du résumé de chaque rapport, qui sera publié dans la revue *Aquatic Sciences and Fisheries Abstracts* et qui figuera dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros de 1 à 900 de cette série ont été publiés à titre de manuscrits (Série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés en tant que manuscrits (Série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros allant de 901 à 1425 ont été publiés à titre de manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 ont été publiés à titre de Rapport manuscrits du Service des pêches et de la mer, Ministère des Pêches et de l'Environnement. Le nom de la série a été changé à partir du rapport numéro 1551.

La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 1741

December 1983

CONTRIBUTION TO THE DEVELOPMENT OF METHODOLOGY FOR SAMPLING AND TAGGING SMALL JUVENILE LOBSTERS (*HOMARUS AMERICANUS*)

by

Brock B. Bernstein

Richard W. Welsford Research Group Limited
Suite One, Second Floor, Collins Court
Historic Properties
1869 Upper Water Street
Halifax, Nova Scotia B3J 1S9

and

Alan Campbell
Invertebrates and Marine Plants Division
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick E0G 2X0

© Minister of Supply and Services Canada 1983
Cat. No. Fs 97-4/1741 ISSN 0706-6473

Correct citation for this publication:

Bernstein, Brock B., and Alan Campbell. 1983. Contribution to the development of methodology for sampling and tagging small juvenile lobsters (Homarus americanus). Can. MS Rep. Fish. Aquat. Sci. 1741: iv + 34 p.

TABLE OF CONTENTS

	Page
Abstract/Résumé	iv
Introduction	1
Tag development and testing	1
Materials and methods	1
Results and discussion	2
Incidental mortalities	2
Tagging success	2
Field mark-recapture test	3
Methods	3
Study area	3
Catch efficiency	3
Initial mortality	4
Mark-recapture sampling	4
Results and discussion	4
Catch efficiency	4
Initial mortality	4
Mark-recapture sampling	5
Summary and conclusions	5
Acknowledgments	6
References	6
Tables	7
Appendix 1	30

ABSTRACT

Bernstein, Brock B., and Alan Campbell. 1983. Contribution to the development of methodology for sampling and tagging small juvenile lobsters (Homarus americanus). Can. MS Rep. Fish. Aquat. Sci. 1741: iv + 34 p.

Several marking and tagging methods were evaluated in the laboratory for small juvenile lobsters (Homarus americanus). The best, a miniature sphyrion tag, had a retention rate of 88% through first molts and 100% through second molts. There was some initial tagging mortality, but no detectable effect on growth or behavior.

This tag was evaluated in a field mark-recapture study that also demonstrated the feasibility of using divers to capture and mark juvenile lobsters. Mortality due to handling and tagging was low (2.5%). There was no evidence for subsequent mortality or effects on catchability, nor for tag loss in the field. The tag is effective on juvenile lobsters.

A comparison of population size estimates derived from the mark-recapture data and from direct sampling by divers showed no discrepancy between the two. The standard error for the direct sampling estimate, however, was an order of magnitude smaller.

Key words: Homarus americanus, lobster, juvenile, tags, growth, density

RÉSUMÉ

Bernstein, Brock B., and Alan Campbell. 1983. Contribution to the development of methodology for sampling and tagging small juvenile lobsters (Homarus americanus). Can. MS Rep. Fish. Aquat. Sci. 1741: iv + 34 p.

Plusiers méthodes de marquage et d'étiquetage de petits homards (Homarus americanus) juvéniles ont été évaluées en laboratoire. La meilleure est celle utilisant une étiquette miniature de sphyrion et dont le taux de rétention est de 88 % aux premières mues et de 100 % aux deuxièmes. On observe quelques mortalités initiales par suite de l'étiquetage, mais aucun effet décelable sur la croissance ou le comportement.

Cette étiquette a été évaluée dans une expérience de marquage-recapture menée sur le terrain, et qui a également démontré la possibilité d'utiliser des plongeurs pour capturer et marquer les homards juvéniles. Les mortalités résultant de la manipulation et de l'étiquetage ont été faibles (2,5 %). Nous n'avons observé aucun indice de mortalités subséquentes ou d'effets sur la capturabilité, non plus que des pertes d'étiquettes dans la nature. C'est une étiquette efficace pour les homards juvéniles.

Une comparaison des estimations d'effectifs de populations dérivées des données de marquage-recapture et d'échantillonnage direct par des plongeurs ne montre aucune différence entre les deux. L'erreur-type de l'estimation par échantillonnage direct est cependant plus faible d'un ordre de grandeur.

INTRODUCTION

The lobster (Homarus americanus) is the basis for an extensive and commercially important fishery in eastern Canada. As such, it has been the focus of considerable research effort (see reviews by Cooper and Uzmann 1980; Dow 1980; Saila and Marchessault 1980). A gap exists, however, in understanding the ecology of juveniles (10-40 mm carapace length) of this species because of the lack of adequate field methodology. The paucity of field studies of juveniles (Cooper and Uzmann 1980) has retarded the process of understanding the relationships between reproduction and recruitment. Consequently, there are little quantitative data on growth and mortality rates or critical habitat requirements in these early life stages of H. americanus. Such information has been obtained for commercial-sized lobsters, partly as a result of tagging studies (see Stasko 1980 for review).

In this study we measured the efficiency of a sampling method (SCUBA diver capture) for small juvenile lobsters, and developed and field tested a tag. Among the tagging and marking methods we evaluated were: dye injection, pleopod clipping, tail punching, tags cemented to the carapace, and a miniature sphyrion tag injected into the dorsal musculature. Our overall goal was to contribute to the development of methods that will permit both short- and long-term studies of juvenile lobsters in their natural habitat.

TAG DEVELOPMENT AND TESTING

MATERIALS AND METHODS

All lobsters used in the experiments were collected during May and June 1982 at McNutt's Island, near Shelburne, Nova Scotia. They were returned to the Fisheries and Oceans Lower Water Street Laboratory in Halifax and acclimated in 14°C sea water for 2 d before testing. This relatively high temperature was used to speed growth and molting. Prior to tagging or marking, each lobster was measured with calipers to the nearest 0.1 mm (carapace length). Lobsters were out of water for not more than 2 min before being placed into sections of a holding tub and observed for abnormal behavior. Each 3-L, 13 x 21 cm tub had its own water supply and air stone (Fig. 1), and sea water flowed through at the rate of 0.5 L/min. Tubs were syphoned daily of any excess food and thoroughly cleaned with dilute Idoform once a week.

At first, two lobsters were held in each tub, separated by mosquito net. This arrangement led to unacceptably high mortalities because the lobsters could see through the mesh and often climbed over it and attacked each other, and/or climbed out of the tubs and escaped. After mid-July 1982, we placed all lobsters in separate tubs.

Throughout the study we noted any abnormal behavior, observed lobsters' overall physical condition (color, movement, injuries), and measured them after each molt. The survival and growth rates of lobsters in each treatment were compared to controls that were captured and handled identically but not tagged. The number of lobsters in each treatment is shown in Table 1.

Fig. 1. The laboratory setup for the tagging study. Large tanks at top are the water sources for the flow-through system. Lobsters were held in the small individual tubs.

The treatments were as follows:

1) Dye. A small quantity (0.25-0.50 cc) of India (blue) ink was injected with a small hypodermic needle into the subabdominal musculature of eight juvenile lobsters.

2) Punching. A small hole was punched (standard paper punch) into the telson and/or uropods of 24 lobsters. The size of the hole was related to the size of the juvenile lobster. Clipping of spines was carried out by cutting one or two of the lower tips of the abdominal spines. Legs and/or pleopods were clipped at the joints.

3) Epoxy. A small amount of underwater epoxy glue was placed on the carapace of 10 lobsters. To distinguish individuals, a numbered piece of vinyl tubing was placed in the glue.

4) Miniature sphyrion tag. A small version of the sphyrion tag described by Scarratt and Elson (1965) was assembled in the laboratory, using vinyl "spaghetti" tubing (Floy Tag Company, Seattle, Washington), nylon filament, and silver wire (30 gauge). We placed a 1-cm section of numbered vinyl tubing on the filament. We then passed the end of the filament through a heat source. This caused the tip to melt back, leaving a locking mass at the end. This was made large enough that the tubing was then moved up against the locking mass at the end and a knot tied behind it (Fig. 2). This prevented the tubing from moving up and down the filament. At this point, the nylon filament was then passed through the heat source, forming another locking mass. Silver wire was shaped into a small anchor around the nylon filament (Fig. 2) similar to, though smaller than, a normal sphyrion tag anchor (Scarratt and Elson 1965).

We injected the tag, using three different-sized hypodermic needles, 18G, 23G, and 25G, to determine if the size of the puncture wound affected tag retention during molting. We inserted one end of the silver wire anchor into the open end of the hypodermic needle and then injected it into the

Fig. 2. The miniature sphyrion tag. Beginning at the top, the components are: locking mass to prevent loss of spaghetti tubing; spaghetti tubing; knot to prevent movement of spaghetti tubing; filament; silver wire anchor; locking mass to hold anchor on filament.

membranous joint, separating the carapace and the abdomen. We found that holding the lobster in one hand in a bent position over the index finger and inserting the tag directly through the exposed membrane and into the muscle at a 45° angle was most effective (Fig. 3). There was a noticeable change in resistance when the needle passed through the muscle and into the thoracic cavity. This caused rapid death. The anchor was seated by twisting and withdrawing the needle to disengage it from the anchor. A gentle tug on the filament then seated the anchor. If the anchor pulled free when tugged, we tried again. Even small juveniles could tolerate two or three tagging attempts, provided the needle did not penetrate beyond the muscle.

RESULTS AND DISCUSSION

Incidental mortalities

There were four sources of mortality related to the experimental setup rather than to the tagging methods themselves: attacks by one lobster on another; escape from the tubs; failures of water circulation or aeration; and handling (Table 1). The majority of deaths (46) resulted from attacks or escapes, and most of these occurred before mid-July when the lobsters were paired two to a tub. Table 1 shows that 31 of these occurred with lobsters that were paired in tubs rather than alone. Since lobsters were held paired for only 1.5 mo and were held alone for 5 mo, it is apparent that mortality among paired lobsters was much more severe. The deaths from failures of water circulation were the result of occasional blockages in the waterlines to individual tubs. The five deaths due to handling occurred when the lobsters pinched the laboratory technician and were inadvertently dropped on the floor.

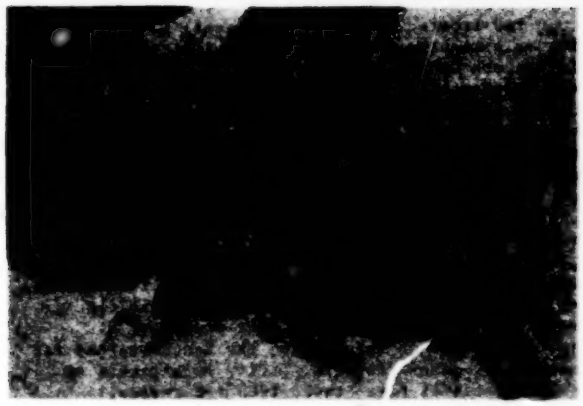

Fig. 3. Tag injection. The needle is inserted into the musculature beneath the carapace at a 45° angle.

Tagging success

1) Dye. Tattooing with India ink was completely unsuccessful. Seven of eight juveniles marked with this method died almost at once. Their legs also fell off immediately. Only the largest lobster survived. In addition, the ink spread rapidly through the abdominal musculature, making a large stain rather than a small dot, and precluding the possibility of marking each lobster individually with a pattern of tattooed dots.

2) Punching. Pleopod and/or spine clipping and tail punching have frequently been used to mark adult lobsters (e.g. Wilder 1963; Chittleborough 1970). Our results demonstrate that these methods are suitable for juvenile lobsters as well. None of the lobsters died as a result of clipping or tail punching. Marks from both these methods were plainly visible after two molts, and would probably persist for at least a further one or two molts. These methods are thus effective for short- to intermediate-term marking programs. Clipping and punching are not only easy methods to use, but the pattern of marks on each lobster can be used to code precise data about the place and time of capture. The five segments of the tail and the numerous abdominal spines and pleopods can be marked in a very large number of combinations, all of which could represent distinct codes. A disadvantage of this method is that it requires a trained observer to recognize the marks.

Clipping and punching did not affect lobsters' behavior either initially after marking or over the longer term. Their movement, appetite, and degree of aggressiveness were indistinguishable from the controls. Clipping and punching also had no effect on growth. A one-way analysis of variance (Table 2) shows that there are no differences in percentage growth increments at molt among any of the tagging treatments and the controls.

3) Epoxy. The epoxy tag had no effect on behavior or growth. It is useful only as a short-term tag since it is shed with each molt. Its advantages are that there is no associated

mortality, it is easy to apply, and it permits the use of highly visible, individually numbered tags.

4) Miniature sphyrion tag. Unlike the clipping and punching methods tested, there was mortality associated with the use of the miniature sphyrion tag. The hypodermic needle can easily puncture a vital organ if it is inserted too deeply or at the wrong angle. When this occurs, the lobster becomes almost motionless and dies within 10 min. If an organ was not punctured, there seemed to be no ill effects from as many as three puncture wounds in the muscle. Lobsters with two or three wounds moved normally, and there were no deaths due to infection. Injecting this tag into small juveniles requires care and practice. We found it was impractical to attempt tagging lobsters smaller than about 20 mm carapace length because it was extremely difficult to properly anchor the tag in these small lobsters. It is possible that an even smaller anchor, inserted with a smaller needle, would have proved more successful.

The miniature sphyrion tag was retained through molts at a high rate, depending primarily on the size of needle used to inject the tag. Table 3 shows that the retention rate was only 50% when tags were injected with a large needle. The retention rate rose to 88% when tags were injected with a medium or small needle. The most likely reason for this higher success rate is that there is less tearing of musculature with the smaller needles and the wound heals more rapidly around the anchor.

We also experimented with two minor modifications of the tag. In the first, we merely shortened the filament from 4 to 2 cm. We had noted that the shed carapace sometimes caught on the spaghetti tag during molt. We shortened the filament to try to avoid this. In the second modification, we left the "arms" of the anchor projecting at 90° rather than folding them in. We hoped that this would seat the anchor more firmly in the musculature. Neither modification improved the retention rate; in fact, the retention rate was slightly lower. We also observed that the shed carapace continued to hang up occasionally on the shorter filament. We do not know what effect this might have in the field. Fannaly (1978) reports that the length of the filament is critical to tag retention at molt in blue crabs. Too short a filament prevented the crab from extricating itself from the old carapace.

We also performed a short-term trial to determine whether the tag was likely to be pulled loose when lobsters sheltered under rocks in the field. We placed four juveniles tagged with the original miniature sphyrion tag in a tank with small boulders. During this period they actively crawled around and under the rocks. All tags were still firmly in place after 1 mo.

There was no detectable difference in percentage growth increments between the sphyrion-tagged juveniles and any of the other groups ($p>0.05$, one-way ANOVA) (Table 2, 4).

The study continued long enough to observe nine second molts. All of these were successful. The retention rate probably increases with time because the wound has healed around the anchor.

FIELD MARK-RECAPTURE TEST

The primary goal of the field program was to conduct a rigorous test, under natural conditions, of the miniaturized sphyrion tag. Two specific concerns related to the efficiency and utility of the tag were: 1) whether the trauma of tagging caused an initial mortality in the first few days after tagging; and 2) measuring the rate of tag loss over time in juvenile lobsters living in their natural habitat. The mark-recapture sampling program designed to answer these questions (see below) allowed us to pursue two subsidiary goals: 1) an evaluation of the assumptions and methodology of mark-recapture techniques applied to juvenile lobsters; and 2) a comparison of density estimates obtained from plot sampling by divers with those produced by a mark-recapture experiment. We emphasize that the sampling program was designed to fulfill the primary goal of testing the tag. The secondary goals were to be addressed only if the data were suitable.

METHODS

All sampling was carried out by direct diver capture of juvenile lobsters. All sampling plots, of whatever size, were marked out under water and a team of divers searched them exhaustively, turning and then replacing every boulder that could be moved. Juvenile lobsters were readily captured as they attempted to escape and were placed in plastic bags under water.

Study area

The study site was a shallow subtidal area along the western shore of McNutt's Island at Shelburne, Nova Scotia (43°38'N; 65°18'W). Previous studies had shown this to be an area of consistently high juvenile lobster densities. The substrate was a mixture of flat and round boulders on a sand and gravel base. Boulder size averaged about 30 cm in diameter, with occasional ones as large as 2-3 m in diameter. The substrate became coarser and the boulders slightly larger along a north-south gradient through the study site.

Catch efficiency

Since all sampling depended on direct diver capture, we measured the accuracy and precision of this method with replicate diver catch efficiency experiments.

The catch efficiency experiments were performed at McNutt's Island. For each replicate, we marked a 10 x 10 m square on the bottom and subdivided it into four 2.5 x 10 m rectangles for ease of sampling. After sampling the area thoroughly, we measured each lobster in the boat and punched its tail, then released it on the bottom. After 2 h, we resampled the area, along with a 1-m wide buffer around the edge. We measured the captured lobsters and noted which ones were marked. Catch efficiency was calculated as the percentage of marked lobsters recaptured.

Initial mortality

Initial mortality in the field after tagging was monitored by placing five freshly caught and tagged juveniles in each of three cages on the bottom at McNutt's Island. Each of the three cages was completely enclosed, with a plywood bottom and nylon window screening for walls and roof. Fouling did not become a problem since experiments were of short duration. Cages were 1.5 m in diameter, and 1.0 m tall. The floor of each cage was covered with small boulders to provide shelter for the tagged lobsters. Survival was monitored after 2 d. We performed two sets of experiments for a total of 30 lobsters.

Mark-recapture sampling

A mark-recapture sampling program was designed as a field test of the modified sphyrion tag. The sampling area was a rectangle approximately 300 m in the longshore direction and 150 m in width. The inshore edge was at about 3 m depth where turbulence from the surf zone made consistent sampling impossible. The offshore edge was at about 9 m depth where the substrate became predominantly sandy and unsuitable for juvenile lobsters.

Ten, 150-m long transect lines were laid perpendicular to shore, each 30-35 m apart. Transects were marked at either end with small surface buoys and secured to the bottom with boulders. Numbered tags were located 15 m apart along each transect forming a grid of 100 points (10 transects x 10 points/transect) numbered from 1-100.

Sampling was conducted on four separate occasions: August 11-18, September 4-8, September 20-24, and October 3-6, 1982 (Table 5). On the first three of these, lobsters were captured, measured, marked, and released; on the fourth and last, lobsters were not marked. Prior to each sampling trip, 30 nonrepetitive numbers between 1 and 100 were selected from a random number table. These represented the numbers of the quadrats to be sampled and ensured samples were random samples of the study site.

At each sampling point, we laid out a rectangular 50 m^2 (5 x 10 m) quadrat. A 10-m line was placed through the middle of the quadrat to divide it into two 10 x 2.5 m sections. Quadrats were always set on the north side of the transect, extending offshore from the numbered tag. This guaranteed we could return to the exact area on a subsequent sampling occasion if necessary.

Each quadrat was sampled by a team of two divers. Each diver inspected one 10 x 2.5 m section. The divers then switched and checked each other's sections. Lobsters were placed in plastic bags and returned to the boat to be measured and tagged.

In the boat, lobsters were placed in a large ice chest filled with sea water. Each was measured (carapace length in millimeters) and tagged with an individually numbered tag. We did not tag lobsters less than 20 mm carapace length since the risk of killing them with the hypodermic needle was too high. All lobsters were returned to the bottom and released inside the quadrat. Divers remained in the area until satisfied that all the lobsters had found shelter.

On the first three sampling occasions, we sampled 30 quadrats (a total of 1500 m^2) or about 3.3% of the total study site area. On the fourth occasion, we sampled 43 quadrats (2150 m^2) or 4.8% of the total area.

On the third sampling period, we set up a double marking experiment by clipping a pleopod on all tagged lobsters released. This permitted us to test for loss of the sphyrion tag. We waited until the third capture because we wished to determine the feasibility of the tagging-recapture methodology and measure recapture efficiency without the potential interference of another marking method.

RESULTS AND DISCUSSION

Catch efficiency

Three replicate catch efficiency experiments were performed on June 30, July 2, and July 3. Replicates 1 and 2 were in areas of easily turned flat rocks on sand base. Replicate 3 was in an area of round rocks piled on top of each other and cemented together with coralline algae. The sites represented the range of habitats in the study area. There was a clear relationship between catch efficiency and substrate type and underwater conditions (Tables 6, 7, 8). Replicate 3, with the lowest catch efficiency, was performed at the limit of workable conditions, with 1-2 m visibility and 2-m swells that created strong surge at the sampling depth (6 m). The effects of substrate type and poor underwater conditions were confounded by the lack of additional replicates, but the results, nevertheless, do identify the range of catch efficiencies that can be expected. The catch efficiency was between 70 and 80% when sampling was carried out during good underwater conditions.

The rank sum and chi-square tests were used to test for significant differences between the marked and recaptured portions of the three pooled samples. This permitted a test of the hypothesis that some size classes were more difficult to capture than others. There is no significant difference between median carapace length of the marked and recaptured samples (Wilcoxan rank sum test, $p > .05$). Neither is there a significant difference between the respective size-frequency distributions (chi-square test, $p > .05$).

Initial mortality

Table 9 presents results of the field experiment to test initial mortality due to tagging. Five of the 30 lobsters escaped. We found no remains inside the cages to indicate these missing lobsters had been killed by the other lobsters or had died as a result of tagging. We think it is highly unlikely that any dead lobsters would be completely consumed by the remaining lobsters. In 18 instances in the laboratory in which one juvenile killed another, not once did the survivor eat any of the remains. We therefore conclude that the missing lobsters escaped from the cages. One lobster shed its tag during molt and two others molted successfully. There was thus no mortality during the few days immediately following successful tagging.

Mark-recapture sampling

Tables 10 and 11 provide a summary of the number of lobsters caught, tagged, and released. It is apparent that most were recaptured in the same quadrat where originally tagged and released (Table 12). We collected additional data not directly related to the tagging field test. The size-frequency distribution was fairly homogeneous across all four capture periods (Table 13), although the density dropped between the first and subsequent captures. The size distribution through the sampling area also appears homogeneous (Table 14). The frequency of large boulders increases along a gradient between transect lines 1 and 10 (personal observation), but there is no associated change in mean lobster size. We also measured size increments between capture for recaptured lobsters (Table 15). Two lobsters appear to have molted, #347 and #392. Their size increases are in the range of 10% of the original size, which conforms to the laboratory results. Other size increments are small enough to be considered measurement error.

We consider tagging effectiveness in terms of several distinct factors: mortality due to handling and tagging, tag loss, percent recapture, tagging effects on catchability, and effects on behavior.

As in the laboratory study, there was a certain level of mortality associated with the process of inserting the miniature sphyrion tags. Table 11 shows that this mortality was low, and dropped from 5.4% of tagging attempts at the first capture to only 2.5% at the third. This compares to an 8.8% mortality rate in the laboratory study. This progressive decrease was due to increased experience in capturing, handling, and tagging. The initial mortality experiment demonstrated that once lobsters are tagged, there is no mortality due to tagging during the following few days. In addition to these direct tests of initial tagging mortality, we performed an additional, indirect, statistical test. Because lobsters were marked on the first capture but not on subsequent captures, it is possible that the experience of being tagged is detrimental. Of the individuals released on a particular day, some will have been caught and marked on previous days, and some not. If mortality is increased by the initial tagging, then lobsters marked for the first time on a particular day will be under-represented in subsequent samples (compared to lobsters caught on that same day but marked previously) (Begon 1979). We tested the hypothesis of no mortality associated with initial marking with the contingency table test described by Begon (1979). We performed this test for captures 2 and 3 (Table 16). The results give no indication that the experience of being tagged for the first time caused any initial mortality. The numbers of recaptures are low, but the G test is not as sensitive to small cell sizes as is the chi-square test. Our conclusions would of course be stronger if they were based on a longer series of recaptures, but the test shows no evidence of tagging-associated mortality after release. This suggests that the only mortality associated with the sphyrion tag in this study was probably due to handling and tagging in the boat, and this dropped as low as 2.5%.

The percentage of lobsters recaptured at each sampling is close to the proportion of the total study area sampled (3.3% for sampling periods 2 and 3, 4.8% for sampling period 4) (Table 17, 18). These percentages are to be expected if lobsters dispersed randomly through the study area after release since the quadrats to be sampled were re-randomized prior to each sampling period. If the random dispersal model is correct, then it would imply that there was no tag loss. Unfortunately, the data are not sufficient to test this model rigorously.

One of the major requirements of tags used for mark-recapture studies is that they not affect catchability. It is possible to test this assumption by using two different capture methods (Seber 1973). Another approach is to test whether individuals that have been captured many times are more or less likely to be recaptured than individuals captured less often. We attempted to detect such a difference in the catch data from captures 2 and 3 with the contingency table test described by Begon (1979). In effect, this procedure tests whether the catchability is independent of catch history. The results indicate that the catch history has no effect on catchability (Table 19). We also compared the size frequency of the recaptured lobsters with those of all tagged lobsters to test for a change in catchability by size after tagging. There is no significant difference between the two size-frequency distributions (chi-square test; $p > 0.9$), and we thus conclude there is no detectable size-related change in catchability due to tagging.

We noted no unusual behavioral differences in the field test between tagged and untagged lobsters. Lobsters appeared to be slightly stunned for about 1 min after tagging, but sought shelter quickly when returned to the bottom. When subsequently recaptured, tagged lobsters were living in the same type of burrow as untagged lobsters. Tagged lobsters were every bit as aggressive as untagged lobsters, and displayed the same type and intensity of escape responses. We found no evidence that the miniature sphyrion tag affected juvenile lobsters' behavior in the field.

SUMMARY AND CONCLUSIONS

The laboratory and field studies demonstrate the miniature sphyrion tag is an effective tag for juvenile lobsters. The immediate mortality due to tagging and handling in the field is low (5.4-2.5%), and there is no evidence of tagging-related mortality after release. The tag-retention rate through molts in the laboratory is 88% at first molt and 100% at second molt. Tagging and capture did not affect catchability, nor did they influence behavior in any detectable way. Growth rates of tagged lobsters in the laboratory were indistinguishable from those of controls, and the two tagged lobsters that molted in the field showed a normal increase in size.

The miniature sphyrion tag compares well to other crustacean tags. Table 20 summarizes the results of a number of other tagging studies. It shows that the miniature sphyrion tag has lower mortality and higher retention rates than most. The major drawback of this tag is the effort required to tag and recapture juvenile lobsters. This is due, however, to the size and behavior of juvenile lobsters, rather than to the tag itself. Small juvenile lobsters must be captured by hand because they will not enter traps.

The laboratory and field studies thus met the study's major goals. Two subsidiary goals were to evaluate the assumptions and methodology of mark-recapture sampling as applied to small juvenile lobsters, and to compare density estimates obtained with mark-recapture methods. These were: 1) that there is no major initial tagging mortality; and 2) that tagging and capture do not affect catchability. We found (see above) that neither of these assumptions was violated. There are, however, several other major assumptions. These are reviewed by Seber (1973) and Begon (1979), among others, and vary depending on the method used. They include: 1) that marking not lower the probability of survival; 2) that all individuals have an equal probability of survival; and, in some instances, 3) that the population is closed. Testing these assumptions requires a greater number of recaptured individuals than we obtained (methods reviewed in Seber (1973)).

We were able, however, to compare the relative values and precision of the population size estimate derived from mark-recapture estimates with that caculated directly from the quadrat samples. This is an interesting comparison because the sampling effort used to derive both estimates was identical. It gives some idea of the relative cost effectiveness of the two approaches. We used Jolly's (Jolly 1965; Begon 1979) stochastic method to estimate population size based on the recapture data. Tables 17 and 21 present the necessary parameters and the final estimate. The best estimate is 4745.20 $\pm$ 2759.39 lobsters in the study area. The estimate based on the quadrat samples gave approximately the same mean estimate, but the error was an order of magnitude lower, 4932 $\pm$ 257 (Table 22). This is a clear indication that quadrat sampling is a more cost-effective method for a given level of sampling effort. The agreement between the two estimates, however, indicates that there was no marked bias in the mark-recapture program, and that the tag is therefore effective for mark-recapture studies.

ACKNOWLEDGMENTS

We thank Barbara Welsford for supervising the laboratory study; Solange Brault for directing the field work; John Stairs and Gary Thurber for field assistance; John Castell and David Casavechia for helpful advice on the maintenance of juvenile lobsters; Holly McNiven and Murray Williams for laboratory assistance; the Gillian MacNab Marine Biology Research Fund for supporting earlier research which laid the groundwork for the present project; and G. Melville and D. J. Scarratt for helpful comments on the manuscript. The study was funded jointly by the Canadian Departments of Supply and Services and Fisheries and Oceans.

REFERENCES

Begon, M. 1979. Investigating animal abundance: capture-recapture for biologists. Univ. Park Press, Baltimore, 97 p.

Chittleborough, R. G. 1970. Studies on recruitment in the western Australian rock lobster Palinirus longipes cygnus George: density and natural mortality of juveniles. Aust. J. Mar. Freshwat. Res. 21: 131-148.

Cooper, R. A., and J. R. Uzmann. 1980. Ecology of juvenile and adult Homarus, p. 97-142. In J. S. Cobb and B. F. Phillips (eds.) The biology and management of lobsters, Vol. 2. Academic Press, New York.

Dow, R. L. 1980. The clawed lobster fisheries, p. 265-316. In J. S. Cobb and B. F. Phillips (eds.) The biology and management of lobsters, Vol. 2. Academic Press, New York.

Fannaly, M. T. 1978. A method for tagging immature blue crabs (Callinectes sapidus Rathbun). Northeast Gulf Sci. 2: 124-126.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika. 52: 225-247.

Saila, S. B., and G. Marchessault. 1980. Population dynamics of clawed lobsters, p. 219-241. In J. S. Cobb and B. F. Phillips (eds.) The biology and management of lobsters, Vol. 2. Academic Press, New York.

Scarratt, D. J., and P. F. Elson. 1965. Preliminary trials of a tag for salmon and lobsters. J. Fish. Res. Board Can. 22: 421-423.

Seber, G. D. F. 1973. The estimation of animal abundance and related parameters. Griffin, London, 506 p.

Stasko, A. B. 1980. Tagging and lobster movements in Canada, p. 141-150. In V. C. Anthony and J. F. Caddy (eds.) Proceedings of the Canada-U.S. Workshop on Status of Assessment Science for N. W. Atlantic Lobster Homarus americanus Stocks (St. Andrews, N. B., Oct. 24-26, 1978). Can. Tech. Rep. Fish. Aquat. Sci. 932.

Wilder, D. G. 1963. Movement, growth and survival of marked and tagged lobsters liberated in Egmont Bay, P.E.I. J. Fish. Res. Board Can. 20: 305-318.

Table 1. Sources of mortality during the tagging study for all types of marks tested. Alone and paired refer to whether lobsters were in separate tubs or paired two to a tub. Numbers in parentheses show the number treated with each type of mark. The last row shows the proportion in each category that died. The sum of the alone plus paired totals adds to more than the total treated because some lobsters were moved from the paired to alone category.

Source of mortality	Control (24)		Sphyrion (57)		Clip/punch (24)		Tattoo (8)		Epoxy (10)		Total
	Alone	Paired	Alone	Paired	Alone	Paired	Alone	Paired	Alone	Paired	
Attacks	0	5	1	7	0	4	0	0	0	1	18
Escape	3	8	6	4	4	1	1	0	0	1	28
Marking	0	0	0	4	0	0	7	0	0	0	11
Water circulation	0	0	3	0	2	0	0	0	0	0	5
Handling	2	0	1	0	1	1	0	0	0	0	5
Molting	0	0	0	0	1	0	0	0	0	0	1
Unknown	1	0	0	0	1	0	0	0	1	0	3
Total	6/11	13/18	11/42	15/48	9/16	6/16	8/8	0/0	1/8	2/4	

Table 2. ANOVA table for one-way analysis of variance of growth increments at first molt. Results indicate no detectable differences among growth increments for the different tagging treatments in the laboratory.

Source of variance	df	Sum of squares	Mean square	F
Among treatments	3	49.7118	16.5706	.7953 NS
Error	57	1186.6456	20.8183	
Total	60	1236.3574		

Table 3. Retention rates of sphyrion tag at molt. The numbers of both successful and unsuccessful molts are shown. Number of successful molts is to the left of the slash.

Needle size	Original tag	Short filament	Short filament modified anchor
First molt			
18 G (largest)	6/6		
23 G	8/0		
25 G (smallest)		11/2	4/1
Second molt			
18 G	1/0		
23 G	1/0		
25 G		7/0	

Table 4a. Growth increments of juvenile lobsters held in the laboratory as controls.

	Initial carapace length (mm)	Growth increment (mm)	(%)
First molt			
	25.9	0.6	2.3
	27.0	4.7	17.4
	30.0	4.1	13.7
	34.9	5.6	16.0
	36.7	2.9	7.9
	39.2	3.3	8.4
	39.4	5.1	12.9
$\bar{X}$		3.8	11.2
s^2		1.689	24.079
Second molt			
	40.5	4.5	11.1
	31.7	0.7	2.2
	33.8	1.5	4.4
$\bar{X}$		2.2	5.9
s^2		2.003	4.636

Table 4b. Growth increments of juvenile lobsters tagged in the laboratory with epoxy.

	Initial carapace length (mm)	Growth increment (mm)	(%)
First molt			
	26.2	3.7	14.1
	29.4	2.7	9.2
	29.8	2.7	9.1
	28.3	4.2	14.8
	31.0	3.0	9.7
	33.3	5.9	17.7
	37.2	3.2	8.6
	48.4	4.6	9.5
$\bar{X}$		3.7	11.6
s^2		1.110	10.341
Second molt			
	32.5	4.3	13.2
	32.5	4.1	12.6
	32.1	5.5	17.1
$\bar{X}$		4.6	14.3
s^2		0.757	2.443

Table 4c. Growth increments of juvenile lobsters tagged in the laboratory by clipping and/or tail punching.

	Initial carapace length (mm)	Growth increment (mm)	(%)
First molt			
	22.4	2.5	11.2
	38.0	4.0	10.5
	32.7	0.9	2.8
	35.3	3.9	11.0
	36.9	1.4	3.8
	39.4	5.3	13.5
	43.5	3.7	8.5
	22.4	2.5	11.2
	26.1	5.8	22.2
	33.1	4.9	14.8
	30.7	3.7	12.1
	35.5	4.7	13.2
	47.5	5.8	12.2
$\bar{X}$		3.8	11.3
s^2		1.578	21.388
Second molt			
	32.8	4.9	14.9
	33.6	2.9	8.6
$\bar{X}$		3.9	11.7
s^2		1.414	4.455

Table 4d. Growth increments of juvenile lobsters tagged in the laboratory with the miniature sphyrion tag.

	Initial carapace length (mm)	Growth increment (mm)	Growth increment (%)
First molt			
	21.4	2.6	12.1
	25.0	2.6	10.4
	25.8	0.5	1.9
	27.7	2.4	8.7
	25.0	2.0	8.0
	28.7	3.3	11.5
	28.8	1.6	5.6
	30.7	4.3	14.0
	30.0	3.4	11.3
	30.0	2.2	7.3
	31.0	2.7	8.7
	31.8	4.2	13.2
	32.0	8.0	25.0
	32.5	2.5	7.7
	32.9	3.3	10.0
	33.3	3.7	11.1
	34.5	4.5	13.0
	34.9	2.7	7.7
	35.5	4.1	11.6
	36.6	5.6	15.3
	36.6	1.4	3.8
	36.7	3.3	9.0
	36.0	3.9	10.8
	38.2	2.8	7.3
	40.6	4.3	10.6
	40.3	2.7	6.7
	40.3	0.7	1.7
	40.5	5.7	14.1
	40.8	5.2	12.7
	40.2	3.6	8.9
	41.0	1.2	2.9
	41.0	4.2	10.2
	42.0	1.2	2.9
$\bar{X}$		3.2	9.6
s^2		1.576	19.949
Second molt			
	44.9	1.4	3.1
	24.0	3.7	15.4
	30.0	3.3	11.0
	43.8	-6.8	-15.0
	31.0	1.5	4.8
	27.6	2.6	9.4
	26.3	3.1	11.8
	36.0	4.0	11.1
	35.0	2.0	5.4
$\bar{X}$		3.9	11.7
s^2		1.414	4.455

Table 5. List of quadrats sampled during each capture period. All quadrat numbers selected from random number table. Each number refers to a unique point in the 100-point sampling grid.

Capture #1	Capture #2	Capture #3	Capture #4
3	3	1	2
4	4	13	6
5	6	16	7
12	10	20	8
16	12	21	9
18	14	27	10
19	19	28	12
22	23	29	13
30	24	36	15
31	25	37	17
32	26	38	21
43	33	39	22
48	37	42	23
52	38	43	24
59	39	49	25
61	48	50	27
63	50	52	30
66	55	53	31
68	58	54	33
69	62	57	37
70	65	59	38
76	66	61	40
77	67	67	42
78	68	69	44
79	71	73	45
80	75	78	48
81	81	81	51
84	84	85	54
86	87	91	55
91	88	95	57
	91		59
			60
			61
			62
			63
			64
			65
			67
			68
			71
			77
			78
			80

Table 6. Catch efficiency experiment, replicate #1. Carapace lengths are in millimeters. M = marked.

Captured and marked	Recaptured	Buffer
14.1	14.2	22.0
21.2	18.2	32.0
21.6	19.1	33.3
22.6	19.7	36.0
22.9	21.0 M	
22.9	21.5 M	
23.2	22.1 M	
25.0	22.5 M	
25.7	23.1 M	
27.7	23.6	
27.9	24.3 M	
28.6	25.4 M	
29.0	27.6	
29.4	28.0 M	
29.4	28.3 M	
32.1	28.4 M	
33.4	29.2 M	
36.4	29.2	
36.7	29.8 M	
36.9	29.8	
37.2	29.9	
55.4	30.0 M	
	31.5	
	33.5 M	
	36.2 M	
	36.3 M	
	36.9 M	
Total 22	27 (17 M)	4

Catch efficiency: 17/22 = 0.77

Table 7. Catch efficiency experiment, replicate #2. Carapace lengths are in millimeters. M = marked.

Captured and marked	Recaptured	Buffer
11.9	11.9 M	26.1
18.3	14.9	36.0
20.4	17.5	
20.5	20.4 M	
21.5	20.5 M	
22.4	21.5 M	
23.0	22.4 M	
23.6	23.1 M	
24.1	24.5 M	
24.5	24.9	
26.6	26.6 M	
27.1	27.1 M	
31.3	31.2	
32.0	31.3 M	
35.0	32.2	
35.9	35.0 M	
36.9	35.0	
39.6	35.5	
41.9	36.9 M	
59.1	39.6 M	
65.6	41.9 M	
	65.6 M	
Total 21	22 (15 M)	2

Catch efficiency: 15/21 = 0.71

Table 8. Catch efficiency experiment, replicate #3. Carapace lengths are in millimeters. M = marked.

Captured and marked	Recaptured	Buffer
14.3	22.5	
29.2	24.0	
29.7	24.1	
30.1	24.9	
30.2	28.2	
30.2	29.7 M	
30.9	29.9	
31.0	30.1 M	
35.6	30.2 M	
40.6	30.9 M	
61.2	31.0 M	
	31.5	
	39.7 M	
	41.5	
	61.2 M	
Total 11	15 (7 M)	

Catch efficiency: 7/11 = 0.63

Table 9. Results of the initial mortality experiment. An asterisk indicates a successful molt.

	Replicate					
	1	2	3	4	5	6
Number tagged	5	5	5	5	5	5
Number alive	4	4	5	4	3	5
Number tagged remaining	4	4	4	4	3	4
Number molts	0	0	1*	1*	0	1

Table 10a. Population parameters by quadrat, capture 1. # = quadrat number; t_1 = date sampled; n = number captured; $seen_1$ = number seen but not captured; m_1 = number of tagged lobsters recaptured; R_1 = number of tagged lobsters released. R_1 includes freshly tagged lobsters as well as recaptures being re-released.

#	t_1	n_1	$seen_1$	m_1	R_1
3	8/12	10	0	-	5
4	8/11	9	0	0	7
5	8/11	12	0	0	8
12	7/12	10	0	0	9
16	8/12	9	0	0	6
18	8/12	9	0	0	8
19	8/15	5	0	0	5
22	8/13	21	0	0	14
30	8/15	5	0	0	5
31	8/13	11	0	0	11
32	8/13	17	0	0	14
43	8/14	10	0	0	8
48	8/15	9	0	0	9
52	8/14	8	2	0	8
59	8/15	10	0	0	8
61	8/14	1	4	0	1
63	8/14	7	0	0	6
66	8/18	10	0	0	10
68	8/16	10	0	0	7
69	8/16	4	0	0	3
70	8/16	2	0	0	2
76	8/17	2	4	0	2
77	8/17	2	3	0	2
78	8/17	9	2	0	9
79	8/17	4	1	0	4
80	8/16	1	0	0	1
81	8/17	1	3	0	1
84	8/18	1	0	0	0
86	8/18	1	1	0	1
91	8/18	1	2	0	2
Totals 30		211	22	0	175

Table 10b. Population parameters by quadrat, capture 2. # = quadrat number; t_i = date sampled; n = number captured; $seen_i$ = number seen but not captured; m_i = number of tagged lobsters recaptured; R_i = number of tagged lobsters released. R_i includes freshly tagged lobsters as well as recaptures being re-released.

#	t_i	n_i	$seen_i$	m_i	R_i
3	9/4	7	0	1	6
4	9/4	11	0	2	8
6	9/4	3	0	0	2
10	9/5	2	2	0	2
12	9/4	8	1	3	6
14	9/4	3	3	0	3
19	9/5	5	0	2	4
23	9/4	4	1	0	4
24	9/5	7	0	0	7
25	9/5	4	0	0	4
26	9/5	3	0	0	3
33	9/10	6	0	0	5
37	9/5	8	0	0	6
38	9/5	6	1	0	6
39	9/6	10	0	0	10
48	9/6	2	0	0	2
50	9/6	7	0	0	7
55	9/6	3	0	0	3
58	9/6	3	0	0	3
62	9/5	3	0	0	2
65	9/6	2	0	0	2
66	9/7	13	2	2	13
67	9/7	5	0	0	5
68	9/7	6	0	1	5
71	9/6	7	0	0	6
75	9/7	2	0	0	2
81	9/8	5	0	0	4
84	9/8	1	2	0	1
87	9/7	2	1	0	2
88	9/7	4	0	0	4
91	9/8	8	0	0	8
Totals 31		160	13	11	145

Table 10c. Population parameters by quadrat, capture 3. # = quadrat number; t_i = date sampled; n = number captured; $seen_i$ = number seen but not captured; m_i = number of tagged lobsters recaptured; R_i = number of tagged lobsters released. R_i includes freshly tagged lobsters as well as recaptures being re-released.

#	t_i	n_i	$seen_i$	m_i	R_i
1	9/20	3	2	0	1
13	9/20	10	0	0	7
16	9/20	7	0	2	6
20	9/21	3	0	0	3
21	9/23	8	1	1	6
27	9/21	3	1	0	3
28	9/21	8	0	0	8
29	9/21	2	1	0	2
36	9/21	14	2	0	11
37	9/21	5	0	0	5
38	9/21	11	1	1	9
39	9/21	4	0	1	2
42	9/21	1	0	0	1
43	9/21	5	0	0	4
49	9/23	5	2	0	5
50	9/23	3	0	2	2
52	9/21	3	0	1	3
53	9/22	6	0	0	6
54	9/22	5	0	0	4
57	9/22	-	-	-	-
59	9/22	6	1	0	5
61	9/22	4	2	0	4
67	9/23	7	0	0	6
69	9/22	4	0	1	4
73	9/22	4	0	0	4
78	9/22	7	1	1	7
81	9/23	4	1	1	3
85	9/23	2	0	0	2
91	9/23	5	0	0	5
95	9/23	1	0	0	1
Totals 30		150	15	11	129

Table 10d. Population parameters by quadrat, capture 4. # = quadrat number; t_i = date sampled; n = number captured; $seen_i$ = number seen but not captured; m_i = number of tagged lobsters recaptured; R_i = number of tagged lobsters released. R_i includes freshly tagged lobsters as well as recaptures being re-released.

#	t_i	n_i	$seen_i$	m_i	R_i
2	10/4	4	0	0	0
6	10/4	12	0	0	0
7	10/4	9	0	0	0
8	10/4	10	0	0	0
9	10/4	6	1	0	0
10	10/4	2	0	0	0
12	10/4	2	2	0	0
13	10/4	5	0	0	0
15	10/4	10	0	0	0
17	10/4	7	3	0	0
21	10/3	7	0	0	0
22	10/3	7	0	0	0
23	10/3	8	0	1	1
24	10/3	4	1	1	1
25	10/3	5	1	0	0
27	10/3	2	0	1	1
30	10/3	2	1	1	1
31	10/3	4	0	2	2
33	10/3	5	0	1	1
37	10/3	10	0	0	0
38	10/3	10	0	4	4
40	10/3	12	0	0	0
42	10/5	7	0	1	1
44	10/5	6	2	0	0
45	10/5	3	2	0	0
48	10/5	4	0	0	0
51	10/6	5	0	0	0
54	10/5	5	0	1	1
55	10/5	4	0	0	0
57	10/5	5	0	0	0
59	10/5	8	0	3	3
60	10/5	6	0	0	0
61	10/6	4	3	0	0
62	10/4	5	0	0	0
63	10/4	3	2	0	0
64	10/4	7	2	1	1
65	10/4	8	0	0	0
67	10/5	11	0	0	0
68	10/5	3	0	0	0
71	10/6	4	0	0	0
77	10/5	7	0	1	1
78	10/5	2	0	0	0
80	10/5	3	0	0	0
Totals 43		253	20	18	18

Table 11. Summary of total number of juvenile lobsters captured, tagged, and recaptured during each capture period. Also included are number killed by handling and tagging. The percent mortality of total tagging attempts is in parentheses.

	Capture 1	Capture 2	Capture 3	Capture 4	Total
# captured	211	160	150	253	774
# tagged	175	134	118	-	427
# killed	10(5.4)	5(3.6)	3(2.5)	5(-)	23
# recaptured	-	11	11	18	40

Table 12. Catch history of all recaptured lobsters. Numbers in the capture period columns refer to the quadrats where lobsters were originally tagged, then subsequently recaptured.

Tag #	Capture period			
	1	2	3	4
73	4	4		
92	3	3		
191	4	4		
217	66	66		
232	12	12		
264	12	12		
293	66	66		64
298	12	12		
306	68	68		
544	19	19		
561	19	19		
57	22		21	
71	5		16	
231	78		78	
299	16		16	
312		50	50	
370		39	39	
504		81	81	
511		50	50	
550	52		52	
795		38	38	
909	69		69	
221	31			31
226	32			31
250	77			77
321		23		23
326	30			30
342			42	42
347	59			59
389		24		24
392			53	54
420		33		33
433			27	27
581		38		38
593		38		38
662			59	59
718		84		59
731			38	38
769		71		38

Table 13. Size-frequency distributions of all lobsters taken at each capture, and of recaptured lobsters.

Size class carapace length (mm)	Number of individuals				
	Capture 1	Capture 2	Capture 3	Capture 4	Recaptures
10	0	0	2	0	0
10-15	7	1	3	4	0
15-20	15	4	7	9	0
20-25	22	17	16	17	3
25-30	40	32	28	55	10
30-35	58	29	38	64	11
35-40	35	35	25	46	7
40-45	12	11	13	28	4
45-50	10	12	7	12	3
50-55	6	6	3	11	1
55-60	1	4	4	4	0
60-65	3	3	2	2	0
65	2	6	2	1	0
Total	211	160	150	253	39

Table 14a. Mean carapace length (mm) and number of lobster captured in each quadrat in capture 1. Numbers after the + are the number of lobsters seen, but not captured. Transect lines are numbered 1 to 10. The last quadrat number on each transect is also shown.

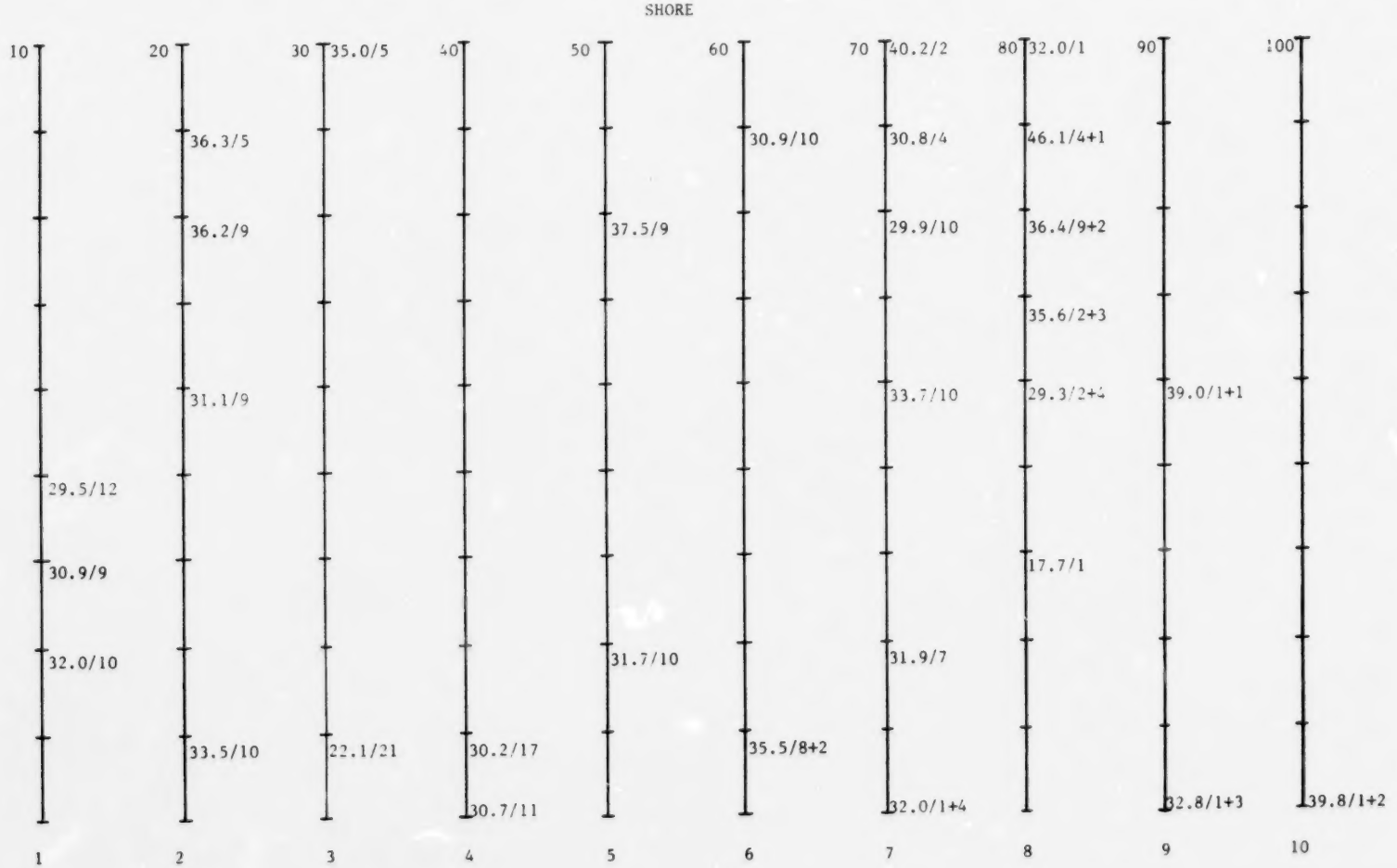

Table 14b. Mean carapace length (mm) and number of lobsters captured in capture 2.

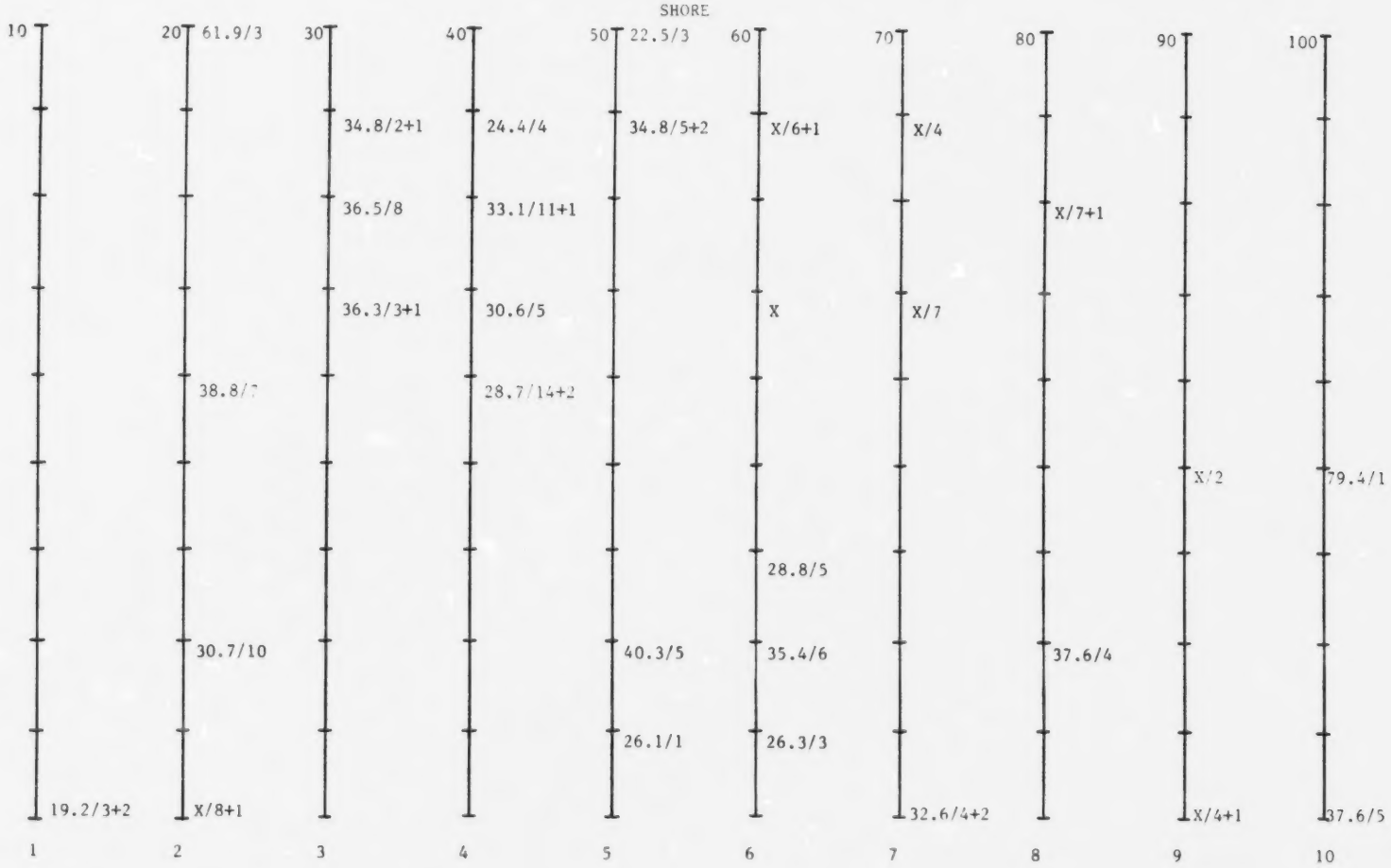

Table 14c. Mean carapace length (mm) and number of lobsters captured in capture 3. X's represent missing data. Data sheets from these quadrats were lost before mean carapace lengths were calculated.

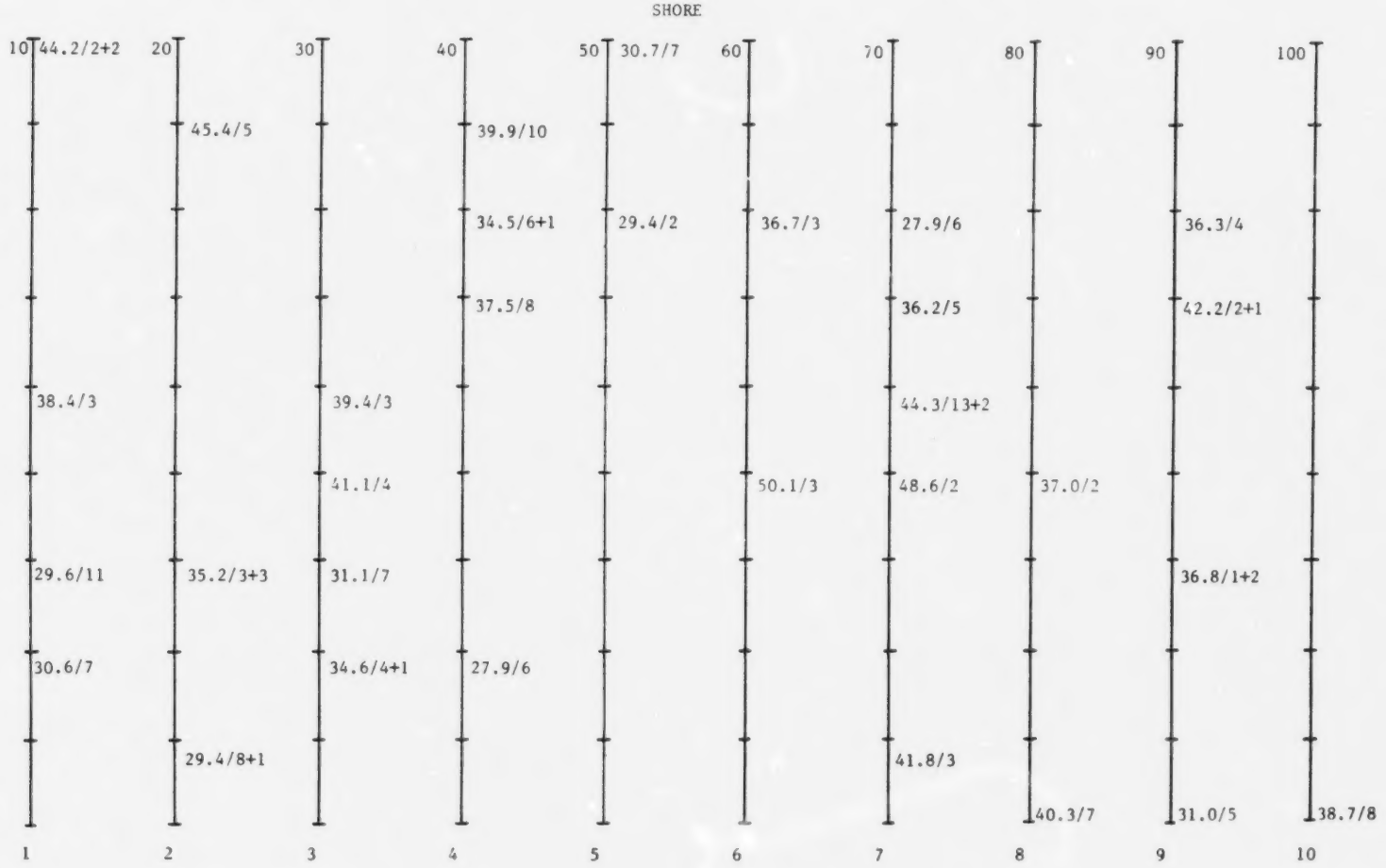

Table 14d. Mean carapace lengths (mm) and number of lobsters captured in each quadrat in capture 4.

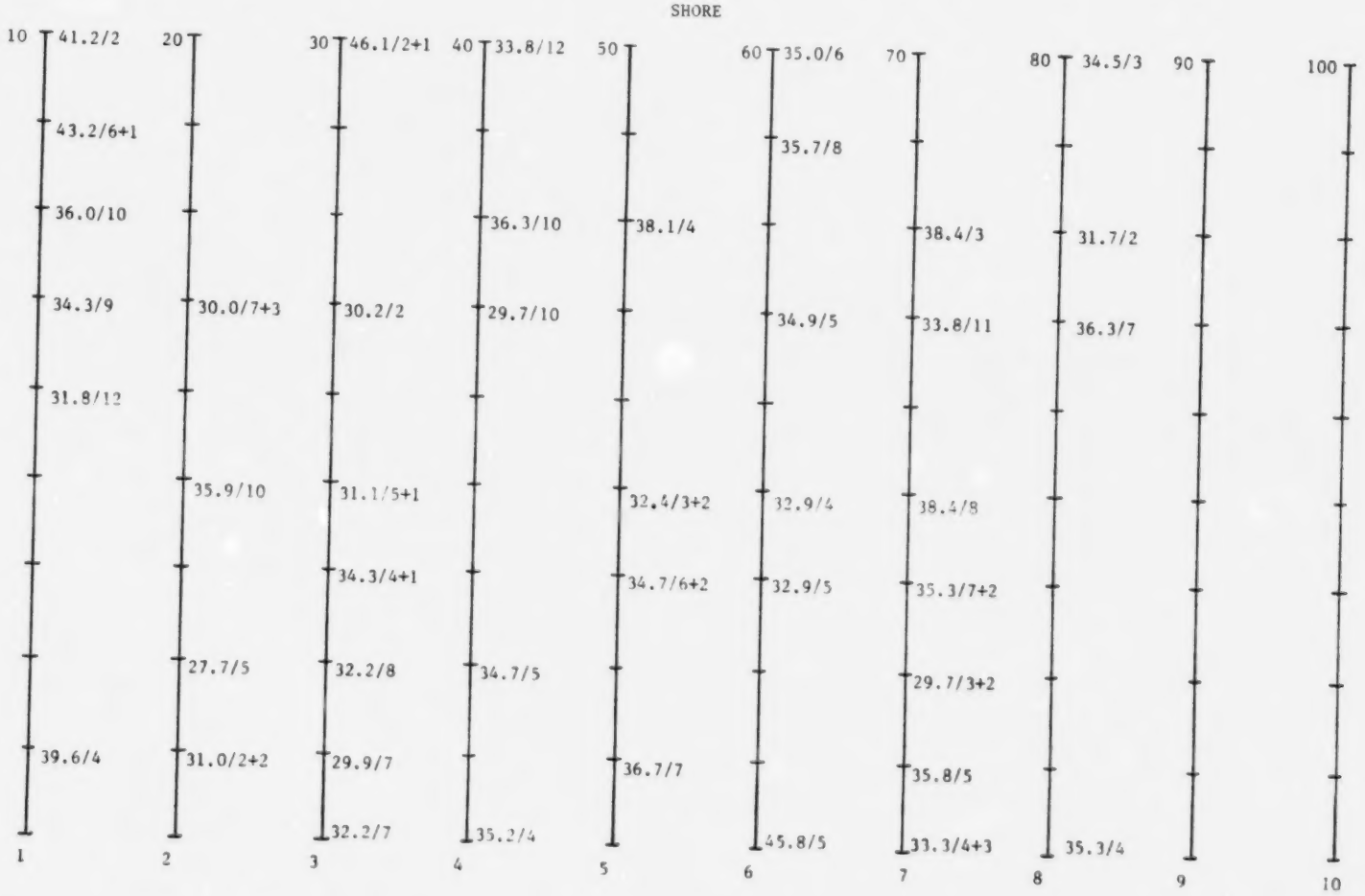

Table 15. Size increments between captures. Most are small enough to be attributed to measurement error. Asterisks by tag numbers indicate missing data. Asterisks by growth increments indicate molts.

Lobster #	Size 1	Size 2	Increment (mm)
73	30.7	30.7	0
92	32.6	32.4	-0.2
191	45.7	46.4	+0.7
217	47.9	46.5	-1.4
232	34.9	34.7	-0.2
264	52.8	52.0	-0.8
298	27.8	27.9	+0.1
306	28.1	27.9	-0.2
544	31.4	30.6	-0.8
561	35.3	35.3	0
* 57	21.9		
71	38.5	38.9	+0.4
*231	41.6		
299	35.0	34.8	-0.2
312	29.3	28.9	-0.4
370	24.5	24.6	+0.1
*504	25.9		
511	28.4	28.8	+0.4
550	22.5	22.6	+0.1
795	34.2	33.3	-0.9
*909	32.2		
221	28.2	27.6	-0.6
226	30.7	30.5	-0.2
250	39.7	39.1	-0.6
293	35.3	34.5	-0.8
321	29.0	28.0	-1.0
326	43.9	43.1	-0.8
342	26.1	26.1	0
347	32.5	36.5	+4.0*
389	37.4	37.3	-0.1
392	26.5	28.4	+1.9*
420	33.2	33.0	-0.2
433	34.2	34.0	-0.2
581	47.4	47.0	-0.4
593	36.9	37.2	+0.3
*662		42.9	
718	36.8	36.6	-0.2
731	26.1	26.1	0
769	44.9	44.2	-0.7

Table 16. Contingency table test for initial mortality associated with tagging. Significance tests performed with the G-test.

	Captured after capture 2	Not captured after capture 2	Total
First captured on capture 2 and released	13	121	134
Recaptured on capture 2 and released	1	10	11
Captured on capture 2 and released	14	131	145

G = 0.194, p = 0.66

	Captured after capture 3	Not captured after capture 3	Total
First captured on capture 3 and released	5	113	118
Recaptured on capture 3 and released	0	11	11
Captured on capture 3 and released	5	124	129

G = 0.012, p = 0.91

Table 17. Summary of recapture parameters. i - capture number; n_i - total number captured; R_i - number of tagged lobsters released (includes recaptures); h - capture prior to i; m_i - number of tagged lobsters recaptured in capture$_i$. The table should be read as: m_{hi} - tagged lobsters recaptured in capture i that were marked in a prior capture h. Thus, 10 lobsters tagged in capture 1 were recaptured in capture 2.

i:	1	2	3	4
n_i:	211	160	150	253
R_i:	174	142	129	-

h	m_{hi}				Total
1	-	10	6	6	22
2			5	8	13
3				5	5
4					
m_i	0	10	11	19	40

Table 18. Percent recapture efficiencies based on data in Table 17. Percentages are calculated as m_{hi}/R_h, for example, 10/174 and 8/142.

h	i			
	1	2	3	4
1		5.75	3.45	3.45
2			3.52	5.63
3				8.87
$m_i\Sigma R_h$		5.75	3.48	4.27

$\Sigma m_i/\Sigma R_h = 8.99$

Table 19. Contingency table test for independence of mark status. Significance tests performed with the G-test.

	Capture 2		
	Times previously caught		
	0	1	Total
Recaptured	12	1	13
Not recaptured	122	10	132
Released	134	11	145

G = 0.336, p = 0.56

	Capture 3			
	Times previously caught			
	0	1	2	Total
Recaptured	5	0	0	5
Not recaptured	113	11	0	124
Released	118	11	0	129

G = 0.91, p = 0.34

Table 20a. Summary of percent mortality, tag loss, growth, and recovery rates for various lobster species. Numbered references are found in the bibliography in Appendix 1. Numbers in open parentheses refer to experiment numbers.

Reference number	Tag type	Mortality		Tag loss		Growth		Recovery rate
		Lab. %	Field %	Lab. %	Field %	Lab. %	Field %	Field %
23	Sphyrion tag	-	-	-	-	-	-	10.3
21	Sphyrion tag	-	-	Subcarapace tag 0	47.0	-	-	46.7
				Abdomen tag 41	64.5	-	-	31.0
26	Dart tag	-	-	-	71.0	-	-	50.0
	Tail punch	-	-	-	-	-	-	19.4
25	Modified sphyrion tag	-	-	0	-	2.7[a]	6.5[a]	-
13	Spaghetti sphyrion tag	-	-	-	-	-	14.2	4.8
5	Sphyrion tag	-	-	-	-	-	15.7 M 13.3 F	-
4	Spaghetti tag	-	-	-	10.0 per molt	-	-	-
3	Rigid plastic	0 (3 mo)	-	0 (3/3 only)	-	low	-	-
	Floy tag FM5	39.0	-	77.0	-	-	-	-
	Modified FM5	33.0	-	87.0	-	-	-	-
	Floy tag FA67	22.0	-	72.0	-	-	-	-
	Wire loop	1) 0	-	20.0	-	-	-	-
		2)20.0	30.4	87.0	-	-	-	12.6
	Floy tag FD67	42.0	-	50.0	-	-	-	-
	Gundersen tag	1)17.0	0	-	-	-	-	-
		2) 0	24.0	8.3	-	5.7	-	33.9
	Sphyrion tag	30.0	-	0	-	12.1 (per molt) 27.0 (per molt)	-	28.7
	Western rock lobster tag	-	-	-	23.0%	-	-	-

[a] = in mm
F = female
M = male

Table 20b. Summary of percent mortality, tag loss, growth, and recovery rates for various crab species. Numbered references are found in the bibliography in Appendix 1. Numbers in open parentheses refer to experiment numbers.

Reference Number	Tag type	Mortality		Tag loss		Growth		Recovery rate
		Lab. %	Field %	Lab. %	Field %	Lab. %	Field %	Field %
9	Posterior suture tag	33.3	-	6.7	-	-	-	-
	Carapace tag	24.0	-	28.6	-	-	-	-
24	Sphyrion tag	-	-	-	-	-	18.1 M 15.0 F	4.4
	Floy tag	-	-	89.0 (short filament) 100.0 (long filament) (4/4)	-	-	-	-

F = female
M = male

Table 20c. Summary of percent mortality, tag loss, growth, and recovery rates for various shrimp species. Numbered references are found in the bibliography in Appendix 1. Numbers in open parentheses refer to experiment numbers.

Reference Number	Tag type	Mortality		Tag loss		Growth		Recovery rate
		Lab. %	Field %	Lab. %	Field %	Lab. %	Field %	Field %
1	Anchor tag	-	-	-	-	-	-	1) 15.3
		-	-	-	-	-	-	2) 19.0
22	Anchor tag	1.0	-	-	-	-	-	4.0
14	Anchor tag	1) 0	-	-	-	-	-	-
	Petersen disc	1) 96.6	-	-	-	-	-	-
		2) 98.2	-	-	-	-	-	-
		3) 87.0	-	-	-	-	-	-
	Control	1) 80.7	-	-	-	-	-	-
		2) 95.2	-	-	-	-	-	-
		3) 82.0	-	-	-	-	-	-
	Petersen disc	4) 20.0	-	-	-	-	-	-
	Control	4) 24.0	-	-	-	-	-	-
	Anchor tag	4) 49.0	-	-	-	-	-	-
	Control	4) 23.0	-	-	-	-	-	-
	Pontamine blue dye	5) 17.5						
	Control	5) 20.0						
11	Uropod clipping	-	-	-	-	-	-	0.5
	Eyestalk clipping	-	-	-	-	-	-	0.26
	Atkins tag	-	-	-	-	-	-	1) $\bar{x}$=54.0
								2) $\bar{x}$= 2.0
								3) $\bar{x}$= 3.4
8	Staining	Neutral red: 0	-	-	-	-	-	-
		Bril. blue 0.5: 65	-	-	-	-	-	-
		Bril. blue 1.0: 38	-	-	-	-	-	-
		Nile blue sulphate: 0	-	-	-	-	-	-
	Atkins tag	$\bar{x}$ = 70.8	0	-	-	-	-	-
	Anchor tag	Red 85.19	-	-	-		-	1) 1.50
		White 46.43						2) 5.2
		Yellow 90.91						
		Blue 50.00						
	Streamer tag	31.1	-	-	-	-	-	-
10	Atkins tag	12.0	-	-	-	-	0.7+3[a] CL/wk	1) 4.6 M
								2) 5.9 F
								2) 9.2 F
								7.5 M
18	Toggle tag	-	$\bar{x}$=56.1	-	-	-	-	1) 4.14
								2) 0.75
								3) 3.31
	Atkins tag	-	-	-	-	-	-	4.67

[a] = in mm
F = female
M = male

Table 21. Population size estimate based on the (1965) Jolly method.

i	r_i	z_i	P_i	M_i	N_i
1	22	-	-	-	-
2	13	11	0.062	130	2099
3	5	13	0.073	346	4745[a]
4	-	-	0.075	-	-

where:

- i — capture number
- r_i — number of marked lobsters released after the ith sample which are subsequently recaptured
- z_i — the number of individuals marked before day i, not caught on day i, but caught again subsequently
- P_i — proportion of marked animals at time t_i : m_i/n_i
- M_i — total number of marked individuals just before time t_i: $\frac{R_i z_i}{r_i} + m_i$
- N_i — total number in the population just before time time t_i : $\frac{M_i}{P_i}$

Standard error of N_3 is 2759.39 (Begon 1979; Jolly 1965).

[a]Best estimate of population size is 4745.20 ± 2759.39; mean ± 1 SE.

Table 22. Population estimate based on quadrat samples (for lobsters ≥20 mm carapace length). Final estimate is for total population in entire 45,000-m^2 study area. All estimates are for mean ± 1 SE.

Capture period	Per quadrat	Scaling factor	Per study area
1	6.37 ± 0.780	900	5733 ± 702
2	5.00 ± 0.508	900	4500 ± 457
3	4.68 ± 0.622	900	4212 ± 560
4	5.60 ± 0.406	900	5040 ± 365
All	5.48 ± 0.286	900	4932 ± 257

APPENDIX 1: ANNOTATED BIBLIOGRAPHY OF RECENT CRUSTACEAN TAGGING LITERATURE

1. Bearden, C. M., and M. D. McKenzie. 1972. Results of a pilot shrimp tagging project using internal anchor tags. Trans. Am. Fish. Soc. 101: 358-362.

   Tag: FD-76C internal anchor tag

   Comments: High recovery rate of 15.3-19.0% in experiments of 12-29 days' average duration. Tag limited to shrimp larger than 120 mm total length. It is not known whether the shrimp can successfully molt and retain the tag even if the insertion point is through the articular membrane. Fouling of tags by barnacles and bryozoans observed frequently. Some bacterial or fungus infection discoloration around the insertion wound.

2. Bottoms, A., and J. Marlow. 1979. A new ultrasonic tag for the telemetry of physiological functions from aquatic animals. Mar. Biol. 50: 127-130.

   Tag: Solid state ultrasonic tag

   Comments: Tag weighs 6 g in seawater. Must be cemented or otherwise attached to animal's surface. Electrodes must be inserted internally. Can monitor heart rate, eye stalk and mouthpart movements, locomotion, etc. Construction details included.

3. Chittleborough, R. G. 1974. Development of a tag for the western rock lobster. Commonwealth Scientific and Industrial Research Organization. Div. of Fish. and Oceanogr. Rep. No. 56.

   Tag: Epoxy resin; tail punching/clipping; tags cut from rigid plastic; Floy tag FMS; modified FMS; Floy tag FAGC; wire loop; Gundersen tag; sphyrion tag; and western rock lobster tag.

   Comments: Lab tests on juvenile rock lobsters over 40 mm carapace length. Developed a new tag, and tested with a field trial. Estimated 77% retention over 39 wk. No data on retention through molts in laboratory tests.

4. Davis, G. E. 1978. Field evaluation of a tag for juvenile spiny lobsters, Panulirus argus. Trans. Am. Fish. Soc. 107: 100-103.

   Tag: Floy FD-68B spaghetti tags

   Comments: Tag loss about 10% per molt for first 3 mo after tagging. Effective for lobsters as small as 35 mm carapace length.

5. Ennis, G. P. 1972. Growth per molt of tagged lobsters, Homarus americanus, in Bonavista Bay, Newfoundland. J. Fish. Res. Board Can. 29: 144-148.

   Tag: Sphyrion tag; ferromagnetic tag

   Comments: Compared growth of lobsters tagged with each type of tag. Concluded that sphyrion tag did not affect natural rates of growth and molting.

6. Fannaly, M. T. 1978. A method for tagging immature blue crabs (Callinectes sapidus Rathbun). Northeast Gulf Sci. 2: 124-126.

   Tag: Floy FD-67B spaghetti tag

   Comments: Lab trials. Found length of leader critical: too short a lead prevents crab extricating itself from old carapace. Even a longer leader hinders molting somewhat. Two crabs molted successfully.

7. Farmer, A. S. D. 1981. A review of crustacean marking methods with particular reference to penaeid shrimp. Kuwait Bull. of Mar. Sci. 2: 167-183.

   Tag: Various crustacean tags

   Comments: A review of what information the ideal tag should produce. Reviews marking methods: tail clipping; eye stalk ablation; immersion; feeding; injection; spraying; tattooing; labeling; tagging: external tags; suture tag; carapace tags; sonic tags; and internal metal tags. Excellent review of all crustacean tags and tagging methods.

8. Farmer, A. S. D., and M. H. Al-Attar. 1981. Results of shrimp marking programmes in Kuwait. Kuwait Bull. of Mar. Sci. 2: 53-82.

   Tag: Staining; Atkins; streamer; anchor tags

   Comments: Quantitative results of long-term marking programs in laboratory and field. Detailed presentation of methods and results.

9. Fujita, H., and K. Takeshita. 1979. Tagging technique for tanner crab long-term tag. Bull. For. Seas Res. Lab. 17: 223-226.

   Tag: Carapace and suture tags

   Comments: Laboratory test. Low retention (8/15) of suture tag through molts.

10. Glaister, J. P. 1978. Movement and growth of tagged school prawns, Metapenaeus macleayi (Haswell) (Crustacea:Penaeidae) in the Clarence River Region of northern New South Wales. Aust. J. Mar. Freshwat. Res. 29: 645-657.

    Tag: Atkins-type tag

    Comments: Depended on fishermen for tag returns plus information on time, place and depth of capture. Low rate of return. Tags became entangled with each other.

11. Ishioka, K. 1981. Shrimp marking trials in Japan. Kuwait Bull. of Mar. Sci. 2: 209-226.

    Tag: Staining; clipping; tracers; external tags threaded through an abdominal segment.

    Comments: Thorough review, including techniques for handling and anesthetizing shrimp. Presents results of laboratory trials and of field marking studies. Discusses use of tags in population dynamics studies.

12. Jefferts, K. B., P. K. Bergman, and H. F. Fiscus. 1963. A coded wire identification system for macro-organisms. Nature 198: 460-462.

Tag: Stainless steel magnetic wire

Comments: Small tags implanted in muscle tissue of juvenile salmon. Rapid injection; no effect on growth. Tag can be detected from several feet away. Organisms must be captured in order to detect tag.

13. Little, E. J. 1970. Tagging of spiny lobsters, Panulirus argus in the Florida Keys, 1967-69. Fla. Bd. Conserv. Mar. Lab. Contrib. 189, 17 p.

Tag: Vinyl spaghetti tag

Comments: Tagged 2415 lobsters. Recovered 4.8%. Mapped movement patterns and measured growth.

14. Lucas, C., P. C. Young, and J. K. Brundrett. 1972. Preliminary mortality rates of marked king prawns, Penaeus plebejus, in laboratory tanks. Aust. J. Mar. Freshwat. Res. 23: 143-149.

Tag: Petersen disc; Floy anchor; pontamine blue stain

Comments: Laboratory study to measure initial and instantaneous mortality of tagging methods. Floy tags caused 50% initial mortality in juveniles and 25% in adults.

15. Maullo, F., A. Emiliani, C. W. Caillouet, and S. H. Clark. 1976. A vinyl streamer tag for shrimp (Penaeus spp.). Trans. Am. Fish. Soc. 105: 658-663.

Tag: Vinyl streamer tag

Comments: Tag has little effect on movement or behavior. Tag was retained in the laboratory and caused no mortality. Survival rate for controls was 91%; streamer tags, 84%; and Petersen tag, 99%. Tag retention was 80% using streamer tags.

16. Peebles, J. B. 1979. Molting, movement, and dispersion of the freshwater prawn, Macrobrachium rosenbergii. J. Fish. Res. Board Can. 36: 1080-1088.

Tag: Sonic tag

Comments: Tags were 6 cm long and weighed 9.1 g. Used to document movement patterns. Receiver has a range of 1.6 km. Tags did not interfere with movement or behavior.

17. Penn, J. W. 1975. Tagging experiments with western king prawn, Penaeus latisculatus Kishinouye. I. Survival, growth, and reproduction of tagged prawns. Aust. J. Mar. Freshwat. Res. 26: 197-211.

Tag: Toggle and Atkins tags

Comments: Field study to determine utility of tags. High initial mortality; good long-term survival. Survival related to healing of tag wound. Growth retarded during first months, but increased during subsequent months.

18. Penn, J. W. 1976. Tagging experiments with western king prawn, Penaeus latisculcatus Kishinouye. II. Estimation of population parameters. Aust. J. Mar. Freshwat. Res. 27: 239-250.

Tag: Toggle tag

Comments: Field trial with 12,000 tagged prawns. Measured catchability and found relationship to temperature. Discusses biological problems in use of recapture data.

19. Prentice, E. F., and J. E. Rensel. 1977. Tag retention of the spot prawn, Pandalus platyceros, injected with coded wire tags. J. Fish. Res. Board Can. 34: 2199-2203.

Tag: Coded wire

Comments: Tagged prawns 15-22 mm carapace length. No effect on growth or survival. All tagged prawns molted at least twice, and tag retention was 95%.

20. Ruello, N. V. 1977. Migration and stock studies on the Australian school prawn, Metapenaeus macleayi. Mar. Biol. 41: 185-190.

Tag: Atkins tag

Comments: Studied relationship between juvenile populations in estuaries and adults at sea. Many releases; returns from 1-22%.

21. Scarratt, D. J. 1970. Laboratory and field tests of modified sphyrion tags on lobsters (Homarus americanus). J. Fish. Res. Board Can. 27: 257-264.

Tag: Sphyrion tag

Comments: Laboratory and field trials. Tag inserted dorsally and in abdomen. No difference in mortality, but dorsal, subcarapace tag retained better during molting. Little apparent effect on growth. Returns from lobsters less than 63.5 mm carapace length extremely low.

22. Schwartz, F. J. 1977. Evaluation of colored Floy anchor tags on white shrimp, Penaeus setiferus, tagged in Cape Fear River, North Carolina, 1973-1975. Fla. Sci. 40: 22-27.

Tag: Floy anchor tag

Comments: Tag effects studied in laboratory. No effect on swimming or burrowing ability. Tagged 30,510 adults in field. Tags retained as long as 7 mo and two molts.

23. Stasko, A. B. 1980. Tagging and lobster movements in Canada, p. 141-150. In V. C. Anthony and J. F. Caddy (eds.) Proceedings of the Canada-U.S. Workshop on Status of Assessment Science for N. W. Atlantic Lobster Homarus americanus Stocks (St. Andrews, N. B., Oct. 24-26, 1978). Can. Tech. Rep. Fish. Aquat. Sci. 932.

Tag: Rubber band; cattle ear tag; vinyl tubing; carapace tag; sphyrion; toggle; and anchor tags.

Comments: Review of use and results of several different tagging methods for adult lobsters.

24. Sullivan, J. R. 1979. The stone crab, Menippe mercenaria, in the southwest Florida fishery. Fla. Mar. Res. Pub. No. 36. 36 p.

Tag: Sphyrion tag

Comments: Tagged almost 19,000 crabs. Returns were 4.4%. Depended on fishermen for tag returns. Tags used to study movement patterns.

25. Sweat, D. E. 1968. Growth and tagging studies on Panulirus argus (Latrielle) in the Florida Keys. Fla. Bd. Conserv. Mar. Res. Lab., Tech. Ser. No. 57. 30 p.

Tag: Modified sphyrion tag

Comments: Tagged 35 adults in laboratory and had 22 successful molts. Tags retained as long as three molts.

26. Winstanley, R. H. 1976. Marking and tagging of the southern rock lobster, Jasus novaehollandiae Holthius off Tasmania. N. Z. J. Mar. Freshwater Res. 10: 355-362.

Tag: Dart tags; tail punching; pleopod clipping

Comments: Dart tags caused bleeding, infection, deformities, and reduced reproductive capacity. Growth also impaired; 19% retention after 2 yr.